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Art. IX.—*On the Bad Lands Deposits of Coburg, Victoria, and their Mapping by Elutriation Methods.*

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(With Plates VIII., IX.)

[Read 11th November, 1926.]

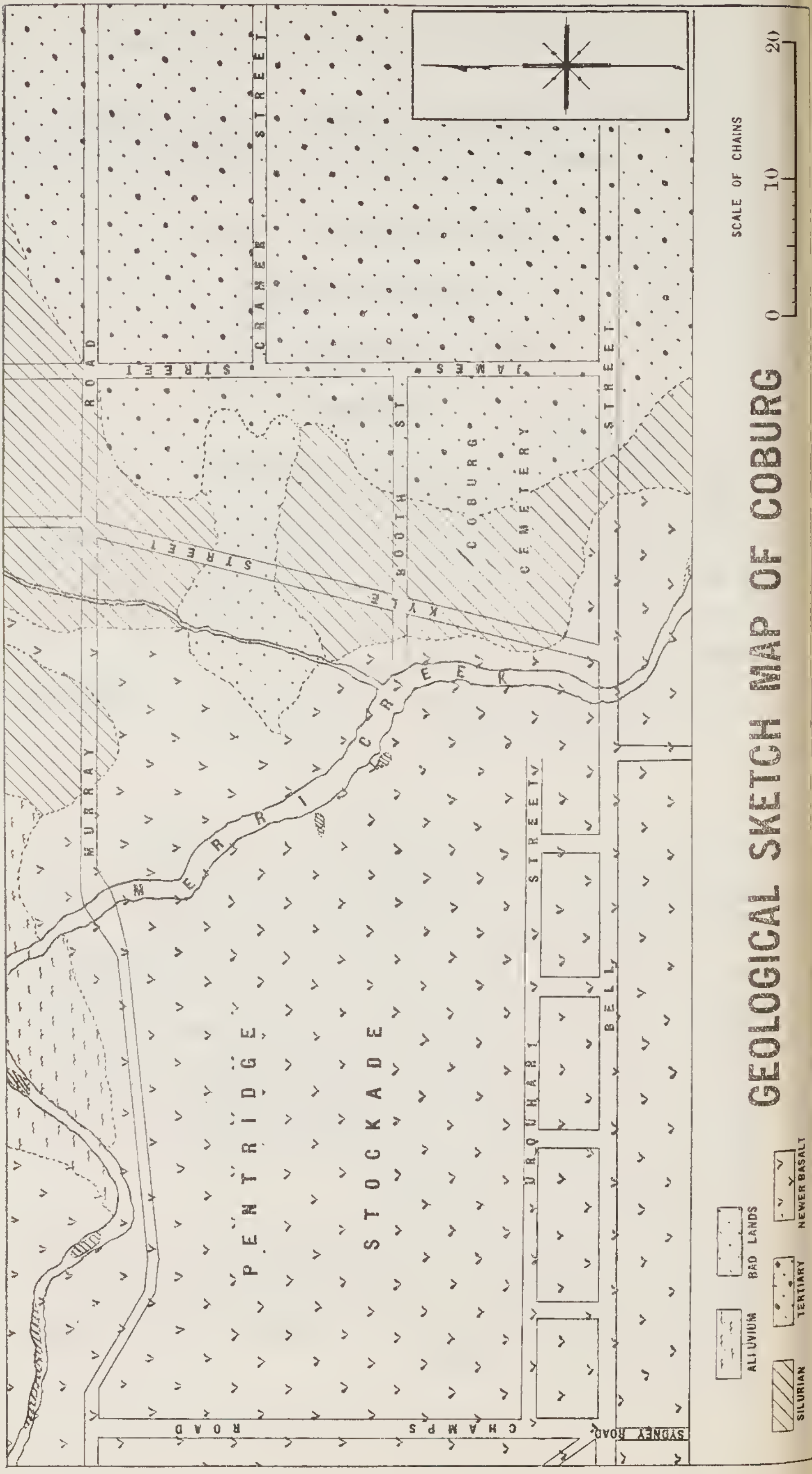
Contents.

I. Introduction.

The work described in this paper was undertaken with a view to elucidating the relations existing between the normal marine Tertiary series and a deposit (hereafter referred to as the "Bad Lands" deposit) associated with it at Coburg.

The locality lies some six miles to the north of Melbourne, to the east of Pentridge Stockade, and occupies a limited area on the western slope of the rising land to the east of the Merri Creek. The Bad Lands area lies to the north of the Coburg Cemetery, to the west of James Street, and to the south of Murray Road.

In passing along Kyle Street, between Bell Street and Murray Road, the locality is easily distinguished by the canyon-like formation due to scouring out of the soft Bad Lands material by running water. This is its most characteristic feature, and has led to its being called the "Bad Lands."
making out some boundaries on account of the paucity of the
In spite of the ease with which the two series may be separated
actual rock exposures, the soil being often the only indication.
In spite of the ease with which the two series may be separated
when forming solid rock faces, as in cuttings, the actual surface indications on both the Silurian and Tertiary were surprisingly alike when examined together.


MURRAY ROAD
CRAMER STREET
JAMES STREET
BOOTH ST
KYLE STREET
COBURG CEMETERY
MERRI CREEK
PENTRIDGE STOCKADE
URQUHART STREET
BELL STREET
CHAMPS ROAD
SYDNEY ROAD
SCALE OF CHAINS
0
10
20
SILURIAN
ALLUVIUM
TERTIARY
BAD LANDS
NEWER BASALT
GEOLOGICAL SKETCH MAP OF COBURG

In addition, to the west of Kyle Street particularly, there is a thin mantle of hill wash material as a result of the scouring of the canyons in the Bad Lands nearer the top of the hill. Such hill wash can only be regarded as a thin film, and insufficiently thick to be represented as a distinct deposit in plan.

Physiographically the area consists of two parts. On the west is a comparatively level area which is almost wholly composed of basalt and which is mainly within the bounds of the Penal Establishment. To the east is an area consisting mainly of Silurian and Tertiary sediments. These two areas are separated roughly by the course of the Merri Creek, which drains both slopes and flows in a southerly direction to meet the Yarra.

The Silurian underlies all the rocks in this locality, and is the basement rock in the Melbourne district. The Silurian consists mainly of sandstone and shales, and specimens from the Coburg area have been already examined and described *(7)*.

The next horizon to be found in this area is the aqueous Tertiary series. Two types of aqueous deposits may possibly be included here: the definite Tertiary such as occurs at Royal Park, Kew, Essendon and Keilor among other localities around Melbourne, and the Bad Lands deposit, which may perhaps be included here as an upper member, though the weight of evidence favours a post-Tertiary age for the Bad Lands.

It is with respect to the origin and relative age of the Bad Lands deposit and its relation to the definite Tertiary, and the use of the elutriation method to distinguish these two, that this paper is mainly concerned.

Several hypotheses[1] have been put forward assigning to the Bad Lands deposit different modes of origin, and different ages, but all hypotheses agree in calling the deposit not older than Tertiary.

The normal Tertiary is best seen at the top of the hill between Murray Road and Bell Street, and immediately south of the poultry farm which faces James Street. Here on the E. and N.E. of the Bad Lands area the Tertiary occurs as a coarse ferruginous gritstone, cemented into a fairly hard rock by dark brown limonite. This type appears to fringe the Bad Lands area on the E., N.E. and N., and then becomes masked by soil and vegetation as it passes over north-westwards to the Silurian.

The Bad Lands deposit consists of much finer-grained material than the Tertiary, and is quite unconsolidated, the limonitic cement of the Tertiary being typically absent. However, there is a characteristic hard capping forming the surface of the Bad

1.—The sources of all but two of these hypotheses are obscure, and they have not been published. The Leaching Hypothesis was a tentative one, used by the writer during field work in 1921. The Basalt-barrier Lake Hypothesis is a personal communication from Dr. H. S. Summers.

Lands area. This is about nine inches in thickness, and immediately under this caked surface capping the Bad Lands material is quite soft and friable, being easily attacked by running water. Three causes may be responsible for this capping, namely:—

1. The concentration of mineral salts by evaporation as a result of percolating waters again reaching the surface by capillarity.
2. The binding action of the matted roots of vegetation.
3. The baking action of the sun at the surface.

Thus for a depth of about nine inches there is a relatively hard and resistant crust, under which, when pierced, the rock is very susceptible to the attack of erosive forces as in the manner suggested by Leach (8).

II. Preliminary Survey of Previous Hypotheses.

Regarding the mode of formation and hence the relative age of the Bad Lands material there has been some diversity of opinion. Quite a number of different hypotheses have been put forward but without much in the way of facts to justify them, and before outlining the work done on the actual Bad Lands material, it may be relevant to mention some of them for testing by actual facts discovered.

The author of one hypothesis states the age as being post-Basaltic, another makes it Tertiary.

A peculiar feature of the Tertiary around Melbourne has led to another hypothesis—the Leaching Hypothesis.[2] It has been noticed in places such as road cuttings, that when the Tertiary is exposed to the subaerial forces, it almost always shows bleaching to some extent at least, and is deprived of its ferruginous cement which has the characteristic brown colour. The material after the leaching out of the iron loses its compact character, becomes soft and friable and of a distinctly lighter colour—light brown to even white. This process has led to the view that the Bad Lands formation was essentially of the same age as the Tertiary marine series, and part of that series which has suffered unduly under the subaerial forces that have been greatly aided in their work of destruction by the agency of Man himself. In support of this hypothesis it was pointed out that the Bad Lands formation differed from the normal Tertiary in the almost complete absence of ferruginous material, the deposit being quite light in colour and correspondingly soft and friable, as a result of the lack of this cement, which makes the Tertiary usually hard and compact. The effective ferruginous cement is pictured as being leached out by percolating waters, which gained considerable assistance by the breaking through of the hard capping (which naturally protects

2.—See footnote page 61.

the Tertiary from denudation) by the construction of plough furrows during the land boom in the 'eighties. At that time it is said that the land on the site of the Bad Lands was subdivided and, to mark the boundaries, plough furrows were run down the slope of the hill, and that the run-off waters naturally sought these depressions, utilising them as channels. Since the hard capping and the binding of grassy vegetation were of no further avail in protecting the Tertiary below, the waters were able to scoop out deep channels in a comparatively short space of time. As then the subaerial agencies were allowed free access to a soft material, they soon leached out a large quantity of iron. In corroboration of this type of action due to weathering, attention is called to road cuttings around Melbourne which have been made comparatively recently, e.g., at La Rose, North Essendon. Here the face of the cutting is furrowed deeply and the material is bleached and looks similar in lithological character to that in the Coburg Bad Lands. It is notable that such alteration by weathering (which is almost certainly the case in these instances) gives rise to light coloured rubbly material; to some extent at least.

This hypothesis postulates that the Bad Land formation is merely the result of weathering of the normal Tertiary, such weathering being due to, and in the first instance promoted by, Man's influence in disturbing Nature's nicely balanced condition of equilibrium when the subdivisional furrows were put in during the land boom days. By upsetting this equilibrium, Man thus gave the erosive forces an opportunity to produce the great scouring out that has taken place. The subaerial forces are still extending their conquest towards the hilltop by a process of headward erosion.

The description and map given in Cook's paper (4) leads one to the conclusion that he regarded the Bad Lands as being portion of the Tertiary Marine Sands.

Another hypothesis is based upon the accumulation behind a temporary barrier. It suggests that the deposit was produced by interruption of the drainage by a basalt flow.[3] Such a condition would give rise to a small lake on the site of the present Bad Lands, and in it there would be deposition of material derived from the Tertiary and Silurian.

III. Nature of the Present Investigations.

The work done in connection with this area includes the making of the mechanical analyses of the Bad Lands material and of the Tertiary associated with it and the microscopical examination of the grades so obtained, together with a field survey of the locality, based in large measure upon the results of the mechanical analyses. The mapping was rendered difficult on account of the surface being covered with grass, and the great

3.—Personal communication from Dr. H. S. Summers, Melbourne University.

scarcity of actual rock exposures. The boundaries to the E., N.E., and S. of the Bad Lands gave less trouble, but the western boundary of the Bad Lands material is exceedingly difficult to place with accuracy on account of the fact that with every rain the Bad Lands material is being washed down-hill to the west and deposited as thin hill wash, completely obliterating the junctions.

Two maps are given: one on a large scale showing the environment of the Bad Lands themselves, and a small locality plan showing the exact position of the area which has been mapped in detail. For geological boundaries outside this area I have relied upon modifications of G. A. Cook's map (4), taken from an unpublished map lent me by Mr. Singleton.

A description of the method used for the mechanical analyses is given as an appendix to this paper.

IV.—Results and Discussion of the Mechanical Analyses.

The outstanding fact brought out by the mechanical analyses is the distinctness between the normal marine Tertiary and the Bad Lands material. The figures show predominance of the silt and clay grades in the Bad Lands deposit, whereas in the Tertiary the coarse grades are dominant. The average cumulative percentage above the lowest limit of the sand grade, i.e., the sum of percentages of all material over 0·1 mm. in diameter, for the Tertiary is 86%, whereas the corresponding figure for the Bad Lands is only 25% approx. This is best brought out by the means of a graph.

The method of plotting the results of the mechanical analyses is that outlined by Holmes (6, p. 216), except that the horizontal scale adopted is not proportional to the logarithms of the diameters, but directly proportional to the square roots of the diameters. The use of the logarithm of the diameter requires the zero of diameter to be represented at infinity. The use of the square roots of the diameters gives the zero of the diameter a finite position on the graph.

Baker (2) has graphed elutriation curves by plotting the actual grade diameters. This method gives a finite zero, but where the particles differ widely in their grade sizes the length of the graph becomes far too great, so that this method is not satisfactory except in cases where the sample shows comparatively small variation in the diameters of its particles, i.e., is well graded. For the purposes of graphing, the cumulative percentage weights were added up from the tables of analyses, and these are given in Table II.

The curves for the Tertiary were found to take up their position as a distinct group on the graph, while the analyses of typical Bad Land material gave a series of curves in an area of the graph quite distinct from the Tertiary. Both series show considerable uniformity, and as the whole area under consideration is small, it was found that the position of the curve in either of these two

		I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Clay	<0·01 mm.	35·8	36·4	36·5	5·6	6·3	3·5	3·1	3·1
Silt	0·01 to 0·1 mm.	43·5	36·5	43·7	6·8	6·5	9·3	11·1	13·2
Sand	0·1 to 1·0 mm.	15·4	18·7	13·1	39·9	40·9	42·2	41·8	38 3
Gravel	>1·0 mm.	5·3	8·5	6·7	47·7	46·3	45 0	44·0	45·5
	Total	100·0	100·1	100·0	100·0	100·0	100·0	100·0	100·1%

		IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII
Clay	<0·01 mm.	43·5	34·4	23·1	32·5	36·2	32·5	59·8	16·6	51·3
Fine Silt	0·01 to 0·05 mm.	28·3	32·6	30·1	28·0	24·8	38·4	17·7	29·8	35·5
Coarse Silt	0·05 to 0·10 mm.	24·6	19·5	13·9	14·0	12 9	17·9	6·4	13·0	6·9
Sand	0·10 to 1·0 mm.	2·5	7·2	21·1	23·3	20·4	10·2	10·2	26·8	5·9
Gravel	>1·0 mm.	1·0	6·3	11·8	2·2	5·7	1·2	5·9	13 8	1·3
	Total	99·9	100·0	100·0	100·0	100·0	100·2	100·0	100·0	100·0%

Table II.

		I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Clay	<0·01 mm.	100·0	100·1	100·0	100 0	100 0	100·0	100·0	100·1°/o
Silt	0·01 to 0·1 mm.	64·2	63·7	63·5	94·4	93·7	96·5	96·9	97·0°/o
Sand	0·1 to 1.0 mm.	20·7	27·2	19·8	87·6	87·2	87·2	85·8	83·8°/o
Gravel	>1.0 mm.	5·3	8 49	6·7	47 7	46·3	45·0	44·0	45·5°/o
Maximum Size of Gravel		2·69	3·23	2·02	4·28	4·02	3·97	4·08	4·16 mm.
Square Root of Diameter		1·64	1·79	1·42	2·07	2·00	2·00	2·02	2·04

TABLE II. *(Continued)*.

		IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.
Clay	< 0·01 mm.	99·9	100·0	100·0	100·0	100·0	100·2	100·0	100·0	100·0 %
Fine Silt	0·01 to 0·05 mm.	56·4	65·6	76·9	67·5	63·8	67·7	40·2	83·4	48·7 %
Coarse Silt	0·05 to 0·1 mm.	28·1	33·0	46·8	39·5	39·0	29·3	22·5	53·6	13·2 %
Sand	0·1 to 1·0 mm.	3·5	13·5	32·9	25·5	26·1	11·4	16·1	40·6	6·3 %
Gravel	> 1·0 mm.	1·0	6·3	11·8	2·2	5·7	1·2	5·9	13·8	1·3 %
Maximum Size of Gravel		2·68	4·15	3·21	2·81	5·29	2·00	2·95	3·54	4·13 mm.
Square Root of Diameter		1·64	2·04	1·79	1·68	2·30	1·42	1·72	1·88	2·03

I.—Bad Lands about 15 inches below surface immediately beneath the hard capping.
II.—Bad Lands about 6 feet below I.
III.—Bad Lands about 10 feet below I.
IV.—Tertiary East of Bad Lands.
V.—Tertiary N.E. of Bad Lands.
VI.—Tertiary South of All-White Poultry Farm.
VII.—Tertiary S.E. of Bad Lands.
VIII.—Tertiary North of Bad Lands.
IX.—Bad Lands 18 inches below surface on slope between Kyle and James Streets.
X.—Bad Lands 18 inches below surface on slope between Kyle and James Streets.
XI.—Bad Lands 18 inches from surface in Creek Section West of Kyle Street.
XII.—Bad Lands 2 feet below XI.
XIII.—Bad Lands 4 feet below XI.
XIV.—Bad Lands 4 feet below XI.
XV.—Bad Lands on hillside between Kyle and James Streets.
XVI.—Bad Lands West of Kyle Street, 80 feet West of Creek.
XVII.—Bad Lands near the contact with basalt.

groups indicated the series to which the sample belonged. It was stated earlier in the paper that great difficulty was experienced in the separating of the two series in the field. The junctions are grass-covered for the most part, and it became necessary to be able to distinguish between the Tertiary and the Bad Lands by examination of the loose detrital material. The usual methods of mapping in the field were found ineffectual. It became necessary to use some method to separate the two series in some systematic manner in the laboratory. To this end the mineral suites in both series were examined, but they showed great similarity, and so no satisfactory distinction could be made on mineral composition except in the few places where the solid ferruginous Tertiary could be found. The only distinction found to hold for the systematic mapping was that provided by the mechanical analyses, and this led to a considerable number of analyses being made with a view to determining the lateral extent in plan of the already known Bad Lands area.

The mapping problem thus resolved itself into that of making the analysis, obtaining the curve for the particular sample and noting the group to which it belonged, and then mapping the locality in accordance with the data so obtained.

Prior to this work being undertaken, the Bad Lands were considered to exist only as far west as the neighbourhood of Kyle Street, but this work has resulted in this deposit being extended across the small tributary valley, and right over to the basalt. This further information lends colour to the last and most probable hypothesis for consideration—namely, that the deposit was formed by a deposition in a lake dammed back by the basalt.

Since the work has been completed, the writer has had the view strengthened that the westerly extension is considerably west of Kyle Street by hearing from an old resident that he remembers the time when there were canyons to the west of Kyle Street exactly similar to those now restricted to the east of Kyle Street, and that he was employed by the landowner to shift the greater amount of the deposit by means of drays.

V. Results of the Microscopical Examination.

The disintegrated material obtained from the elutriator was examined under the microscope using clove oil as a mounting medium, its index of refraction being similar to that of Canada balsam, 1·544. The results of the microscopical examination showed the similarity in mineral content of the Tertiary and Bad Lands. The mineral assemblage is found to be largely identical also with that of the Silurian as given in Langford's paper (7).

It was found early that the mineral content showed an overwhelming preponderance of the minerals quartz and felspar, so much so as to make the discovery of the less common minerals difficult. To facilitate the search for these accessory minerals large samples were treated (9) with bromoform (S.G. 2·84) in order to float off the lighter quartz and felspar and leave the heavy residue concentrated for closer examination.

The most striking essential difference between the Tertiary and the Bad Lands material, however, lies in the presenee of the limonitic cement in the Tertiary, while the Bad Lands are distinetly lacking in this eonstituent.

The minerals eommon to both the Tertiary and Bad Lands are as follow:—

Quartz.—In great abundance, oecurring in irregular grains without crystal boundaries. Low refractive index, no cleavage and many showing 1st order yellows under polarized light. Many good uniaxial interference figures and of positive sign.

Felspar.—Also greatly abundant, but showing much cloudiness due to weathering. Biaxial, R.I. low, and showing low polarization colours. A few show somewhat vague indications of lamellar twinning, and may be plagioclase.

Tourmaline.—This is a fairly abundant aeeessory, oceurring in rectangular grains, with refractive index higher than quartz. Pleochroism strong, and with straight extinction. Uniaxial figures and negative sign. The grains are quite free from alteration.

Topaz.—R.I. higher than quartz, straight extinetion. Biaxial and with basal cleavage. Occurs in rounded grains.

Zircon.—Many grains show erystal faces. High R.I., and showing whites of high order. Uniaxial. This mineral is common as an accessory.

Rutile (probably).—Reddish brown, rounded grains, with high R.I., and with high polarization eolours. Uniaxial.

Iron Ores.—Occurring as minute blaek opaque grains of irregular shape, probably magnetite and ilmenite.

Micas.—Biotite oecurs rarely, as crystals with frayed ends and basal cleavage, markedly pleochroic and with high polarization colours. There are also colourless, ragged-ended crystals, with characteristic cleavage of the micas, high colours and biaxial figure, and hence probably museovite.

Andalusite.—Occurs in rounded prismatic grains, with inclusions present. The mineral was colourless, and so showed no pleoehroism. Cleavage present, but not very distinct. R.I. fairly high, low polarization colours. Biaxial and showing straight extinetion.

Of the minerals mentioned quartz is by far the most important in quantity, the felspar being very eommon but subordinate to the quartz. Of the minerals present in small amounts the most conspicuous is the tourmaline, although zircon is quite common, the others mentioned being quite subordinate, while the micas are only rarely found.

The limonite in the Tertiary occurs as a brown cementing material coating the grains of other minerals. The friable nature of the Bad Lands may be attributed to the lack of this ferruginous cement.

VI. Summary of the Evidence obtained at Coburg.

1. All three series (Silurian, Tertiary, and Bad Lands) have similar mineralogical composition with the notable exception of the presence of limonitic cement in the Tertiary. When this limonite becomes leached out, as it does on weathering, the Tertiary assumes the appearance of the Bad Lands.

Minerals present include quartz, felspar (perhaps including plagioclase), tourmaline, rutile, topaz, zircon, iron ores, micas, and probably andalusite.

2. The mechanical analyses show the Bad Lands and Tertiary to be distinct, i.e., the Tertiary is coarse and the Bad Lands fine.

3. The Bad Lands material is homogeneous in grain size in vertical sections excepting for the presence of the thin basal conglomerate and the immediate surface soil.

4. The Bad Lands material is visibly unconformably overlying the Silurian, but no section can be seen at Coburg showing Tertiary and Bad Lands in stratigraphic contact, although the mapping demonstrates their unconformable relations.

5. The Silurian occurs close to the surface near the top of the hill, but further down the hill the thickness of the Bad Lands deposit becomes 12-15 feet.

6. The Bad Lands material shows bedding, and may be considered to be *in situ*.

7. The Tertiary is ferruginous: the Bad Lands not ferruginous.

8. The Bad Lands material is unconsolidated, while the Tertiary normally is consolidated.

9. No fossils have so far been obtainable from either series at Coburg. A doubtful sponge spicule was noted in the microscopical examination of the sands from the Bad Lands.

In examination of the Bad Lands material under the microscope organic remains were found. These were diatoms belonging to the genera *Fragillaria*, *Melosira* and *Synedra*, but it was found that they came in with the water during the elutriation process and are therefore valueless as fossil evidence concerning the Bad Lands.

10. Pebbles in the basal conglomerate of the Bad Lands include some of the material belonging to the marine Tertiary. It follows that the Bad Lands are post-Tertiary in age.

11. The Bad Lands material is notably free from basaltic detritus. There is an absence, as far as it is observable, of basaltic pebbles associated with the Bad Lands, although there is a great abundance of pebbles from both Tertiary and Silurian. However, near the western limit of the deposit the material includes detritus derived from the basalt.

VII. Discussion of Hypotheses in the Light of New Evidence.

With this evidence it is possible to review the two hypotheses mentioned at the beginning of this paper. The first is the hypothesis which postulates that the Bad Lands material was produced by leaching from the original Tertiary *in situ*, aided by Man's influence in piercing the hard protective capping. Although the mechanism whereby the water got down below the hard capping is given as due to the putting in of plough furrows along subdivisional boundaries in the boom period, yet such procedure is not likely. What probably happened and realised the same ultimate result even more effectually was that the upper surface was shovelled off and carted away on account of the builders' great demand for this particular kind of material constituting the hard capping. There is abundant surface indication that such illicit practices occurred before the subdivisional survey was made. The building boom was flourishing in 1885-6, and this hard capping was probably removed at this time. The fact that the survey took place subsequently in 1888 is in accord with these considerations.

Certain of the evidence obtained at Coburg agrees with the leaching hypothesis, e.g., the mineralogical similarity between the Tertiary and the Bad Lands deposit, the absence of limonite in the latter being pictured as due to the leaching out of the cementing medium. This accords also with the unconsolidated friable nature of the Bad Lands, the absence of fossils and the persistency of its faint bedded nature.

The objections are mainly those appearing on inspection of the mechanical analyses. There should be no basal conglomerate containing rounded Tertiary pebbles. If the Tertiary marine deposit were the parent rock undergoing leaching, the coarser grades should still be present. The simplicity of this hypothesis is commendable, but while it is on this account interesting, the facts shown by the mechanical analyses are difficult of explanation. The lack of the sand grade (1·0—0·1 mm.) in the Bad Lands is considered to show the distinctness between the Bad Lands material and the Tertiary. The question may well be asked, why is it that the Bad Lands deposit lacks the coarse sand grade percentage which characterizes the Tertiary? The mechanical analyses show the percentages down to the lower limit of the sand grade to be 25% and 86% for the Bad Lands and Tertiary respectively.

The other hypothesis for consideration is that which postulates that the Bad Lands material was deposited in a lake formed subsequently to the Newer Basalt, behind a barrier caused by one of these flows. Such a mechanism would readily accord with the mineralogical similarity between the three series—the limonite probably disappearing in solution as in the last hypothesis. The reason that there is a lack of the coarser grades in the Bad Lands may be that the Silurian material and only the *finer* grades of the Tertiary were carried into the lake, the currents being not strong enough to transport the coarser grades. This would give a higher sand percentage in the Tertiary than in the Bad Lands.

The site of the lake was probably determined by the presence of the old valley mentioned by Cook (4). This old valley must have been cut down right through the Tertiary to the Silurian beneath, before the deposition of the Bad Lands material commenced. This is shown by the fact that the Bad Lands is clearly resting directly on the Silurian, and the basal conglomerate of the Bad Lands Series contains pebbles unmistakably belonging to the Tertiary.

Such a deposit as the Bad Lands is like a recent lake deposit, being unconsolidated, since it has never had compression due to superincumbent rock. The uniformity with the Silurian is readily explained, and so also is the basal conglomerate with its rounded pebbles of the Tertiary. The homogeneity of the Bad Lands material in vertical section is satisfied, and so also is the slight bedded nature of the deposit.

VIII. Conclusion and Acknowledgments.

It is concluded, so far as can be gleaned from the evidence at present obtained at Coburg, that the Bad Lands are certainly younger than the marine Tertiaries, and also very probably the result of deposition of detrital material from the neighbouring Tertiary and Silurian in a lake formed in post-Newer Basaltic times.

In conclusion, the writer wishes to gratefully acknowledge his indebtedness to Prof. Skeats for much valuable criticism of the work in its various stages; to Dr. Summers, for much helpful discussion of the problems which have arisen from time to time; and to Mr. Singleton, M.Sc., and Dr. Stillwell, for useful suggestions in the laboratory work.

IX. Appendix.—Description of the Apparatus and Method used in making the Mechanical Analyses.

The mechanical analyses were done by the method of elutriation for the three finest grades, viz., clay, fine silt and coarse silt (i.e., below 0·1 mm.), while coarse grades, gravel and sand, were separated by wet sieving in a circular mesh sieve.

The form of elutriator used first was similar to that described by Crook (5), but this was later discarded in favour of a single-vessel on account of the difficulties in working the particular vessels in use. The single-vessel type used is similar to that described by Holmes (6), where Prof. Boswell's description (3) is quoted. Two of these elutriators were used; one of large diameter, about 8 inches, for estimation of the clay grade, and another of approximately 3 inches diameter for the fine silt and the coarse silt grades.

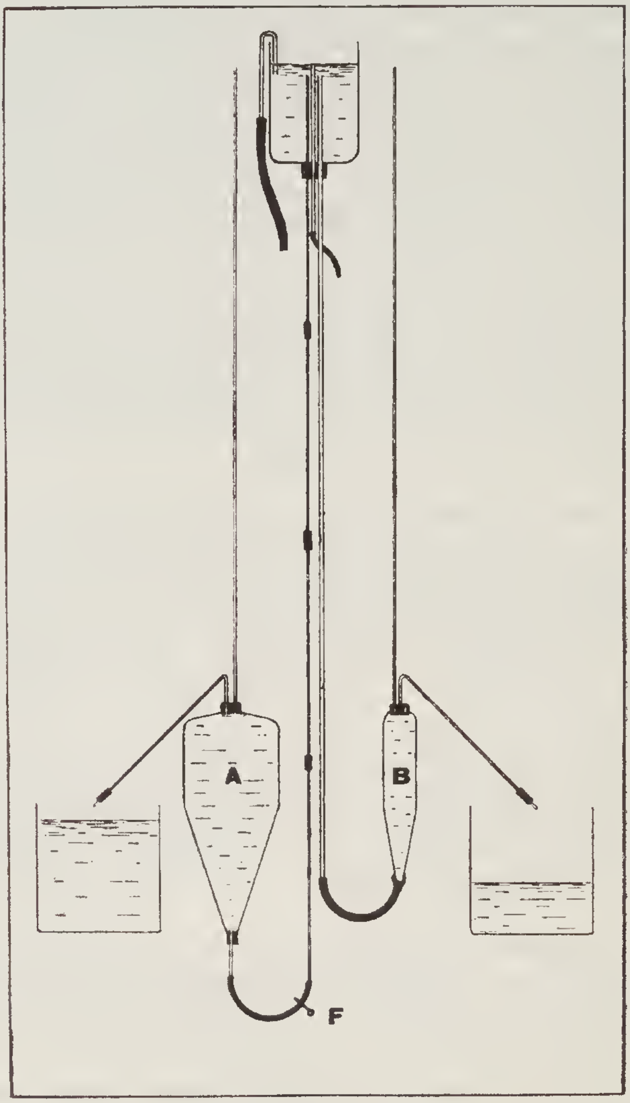


Fig. 2.

The internal diameter of the vessel B (about 3 inches) was determined by measuring the volume of water discharged while the level of the water in the vessel fell through a known height. Then the diameter thus found was used to determine the rate of outflow from the vessel in order to give the required velocity of upward flow within the vessel (1·79 mm. per sec. for fine silt between the limits 0·01 and 0·05, and 7 mm. per sec. for coarse silt between 0·10 and 0·05 mm.). Having a reservoir supplying water under constant head and a jet of suitable size, about 1 mm., the screw clip is opened and adjusted by trial and error until the calculated rate of outflow is obtained for one particular jet. To find the required height in the manometer the method of graphing used by Baker (1) was found to be very satisfactory. The height of the column in the manometer is then marked so that for future determinations all that is necessary to obtain that particular rate of flow is to use the same jet and open up the screw clip until the manometer column reaches this point. In this way two different rates were marked—one to run off the fine silt and the other to run off the coarse silt. The larger clay elutriator A (about 8 inches diameter) was treated in the same way and adjusted to give an upward flow of 0·15 mm. per sec. The height of the water level in the manometer was then marked as before to facilitate regulation for the same flow in future determinations.

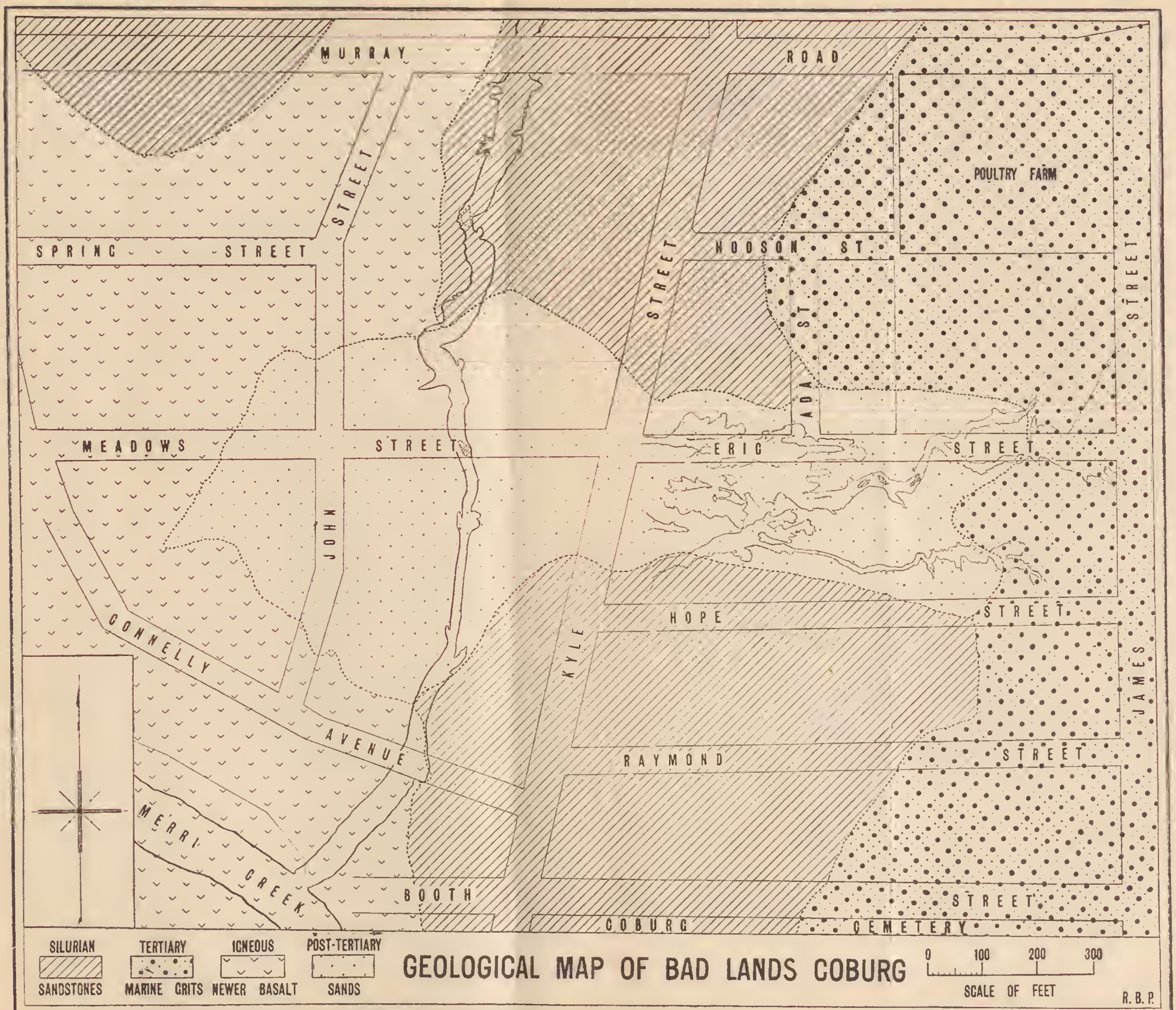
It was found that though the height in the manometer tube appeared stationary, yet after a space of two or three hours the level would show movement. As it is desirable to be able to allow the elutriation process to go on without attention, any such variation is unsatisfactory. This variation was overcome by using a small outlet feed pipe, the maximum capacity of which was scarcely greater than that required by elutriation at 0·15 mm. per sec. through the vessel A. Under these circumstances the controlling clip F needed only slight adjustment, and the flow was found to remain steady. A rubber inlet pipe was first used, but was discarded in favour of glass of similar bore. Under these conditions the manometer level was found to be quite stable for long periods.

The method of calculating the required rate of flow from the figures 0·15 mm. per sec. for fine clay up to 0·01 mm. in diameter, 1·79 mm. per sec. for fine silt up to 0·05 mm., and 7 mm. per sec. for coarse silt up to 0·10 mm. diameter, gives rates of flow which bring over grades which are only approximately of the stated diameter. The maximum diameter of the particles actually coming over for each grade was measured under the microscope, and the corrections made for each of the grades were applied in the plotting of the curves in the graph. For example, it will be noted on Plate IX. that the ordinate representing the actual grade run off, is displaced a little from the ordinate representing the grade calculated to run off, and the plotting is done on these displaced ordinates, which are shown in broken lines. Having thus calibrated the particular apparatus in use the mechanical analysis may be proceeded with.

A sample of the Bad Lands material weighing several kilograms, after being air-dried on a tray, was quartered down to a sample of 15 to 25 gms., and this was placed in a tared weighing bottle and dried as far as possible at 110°C. A weighing bottle must be used on account of the hygroscopic nature of the fine clay forming part of the material. After weighing, the sample must be prepared for elutriation by disintegration into the grain sizes in which it was laid down in the original sediment. On this account no hard pestling is permissible. It was found satisfactory to plunge the weighed material at 110°C. into a beaker of cold water, whereupon the small clods fall away into powder. Complete disintegration is promoted by warming gently to a boil, and, after cooling, by the addition of a little ammonia to deflocculate the clay.

Then with the clay elutriator A half full of water, wash the prepared sediment into it. Fill the elutriator completely, allowing time to elapse for all grades but the clay to settle below the uniformly wide part of the vessel. Start the water flowing at the required speed according to the manometer, as calibrated with the particular jet for running off the finest grade, namely, the clay (less than 0·01 mm.). The clay will be run off continually, leaving behind the three other grades, sand, silt and gravel. The conclusion of the running off of any particular grade is known to be complete when the outlet water is clear and quite free from suspended particles. Difficulty was experienced in estimating the clay. Three methods, all more or less direct, were tried, but none was completely satisfactory. The first was by evaporating down the complete volume of clay water. This was a very tedious, long and messy process requiring much attention, and thus found to be very unsatisfactory. An alternative tried was to evaporate down an aliquot part of the whole volume of clay water. This involves accuracy in measuring the volumes, as the clay water may be 15-20 litres or more, and such a bulk introduces error. The third method was that of precipitating all the clay by the addition of the electrolyte (ferric chloride) and subsequent filtration. The very large volume of liquid is too much to deal with, and the precipitation is not as complete as could be desired. After trying these methods it was found more expedient to estimate the clay indirectly.

The weights of gravel, silt and sand were added together, and subtracted from the weight of the sample, thus giving the weight of the finest grade (clay). As a check against this the elutriator was discharged at the conclusion of running off the clay and the weight of (sample minus clay) directly found by weighing. After making this check the (sample minus clay) was returned to elutriator B, and the flow regulated for fine silt. After the fine silt had been completely run off the elutriator was discharged, and the coarse silt, sand and gravel weighed together. This coarse silt, sand and gravel is then placed in elutriator B, and the flow regulated for coarse silt. This runs the coarse silt off, and leaves the sand and the gravel in the elutriator. The elutriator is then discharged into a 1·0 mm. circular mesh sieve, and the


MURRAY
ROAD
POULTRY FARM
STREET
SPRING STREET
HOOSON ST.
STREET
ADA ST
STREET
MEADOWS STREET
ERIC STREET
JOHN
KYLE
HOPE STREET
JAMES STREET
CONNELLY AVENUE
RAYMOND STREET
MERRI CREEK
BOOTH STREET
COBURG CEMETERY
SILURIAN SANDSTONES
TERTIARY MARINE GRITS
IGNEOUS NEWER BASALT
POST-TERTIARY SANDS
GEOLOGICAL MAP OF BAD LANDS COBURG
0 100 200 300
SCALE OF FEET
R. B. P.